Research Note

Exploratory studies on social spaces between humans and a mechanical-looking robot

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The results from two empirical studies of human–robot interaction are presented. The first study involved the subject approaching the static robot and the robot approaching the standing subject. In these trials a small majority of subjects preferred a distance corresponding to the ‘personal zone’ typically used by humans when talking to friends. However, a large minority of subjects got significantly closer, suggesting that they treated the robot differently from a person, and possibly did not view the robot as a social being. The second study involved a scenario where the robot fetched an object that the seated subject had requested, arriving from different approach directions. The results of this second trial indicated that most subjects disliked a frontal approach. Most subjects preferred to be approached from either the left or right side, with a small overall preference for a right approach by the robot. Implications for future work are discussed.

Keywords: Social robot; Social spaces; Human–robot interaction; Android and robot appearance

1. Introduction

In the near future, robots may be required to interact closely with people. A robot that is to find a place in a human-inhabited environment may need to display socially acceptable behaviour (cf. Thrun 1998, Nakauchi and Simmons 2002, Goetz and Kiesler 2002, Severinson-Eklundh et al. 2003, Fong et al. 2003, Scopelliti et al. 2004, te Boekhorst et al. 2005 and Dautenhahn et al. 2005 for recent investigations into humans’ reactions to robots). If a robot is instead irritating, unsettling or frightening, this may result in its rejection and consignment to the scrap heap. So how can a robot behave in a socially acceptable manner?

The two main social components of any robot designed to interact with humans are appearance and social behaviour. It is possible to place robots on an anthropomorphic scale that varies from mechanistic to humanlike, as suggested by Mori (1970), Woods et al. (2004) and Goetz et al. (2003). Hinds et al. (2004) studied the effect of robot appearance on people carrying out a joint task and found that more humanlike robots are treated more politely.

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Moreover, participants tend to treat mechanistic-looking robots subserviently, with less social interaction, and expect them to be less reliable and less able. There is evidence to support the view that people respond to certain social characteristics, features or behaviours exhibited by less humanlike robots (Breazeal 2002, Okuno et al. 2002, Kanda et al. 2003). Reeves and Nass (1998) provided evidence that even in interaction with computers, people exhibit aspects of social behaviour. However, a study by Friedman et al. (2003) has shown that people do not treat or view the Aibo™ robot dog in the same way as a real dog, especially with respect to moral standing. Thus, it is unlikely that people will react socially to robots in the same ways that they react to people or animals in comparable contexts (Norman 1994, Khan 1998, Dryer 1999, Dautenhahn 2002, Dautenhahn et al. 2002).

Inspired by Mori’s observations on the ‘uncanny valley’ (Mori 1970), Goetz et al. (2003) and Minato et al. (2004) proposed that, if a particular robot’s appearance and behaviour were mutually consistent, it would be more acceptable and effective at interacting with people (cf. Woods et al. 2004, MacDorman 2005). Socially acceptable robot behaviour therefore should encompass various issues related to robot appearance, behaviour and communication abilities. To address these issues empirically, it was necessary to limit the scope of these exploratory studies to a few basic situations and only one robot appearance type was used: a commercially available PeopleBot™, which looks mechanistic. This has the advantage that participants’ initial expectations of the robot’s social behaviour are relatively low.

Social spaces among people have been found to reflect social standing, status and intimacy (Hall 1966, 1968). The current studies were inspired by the notion of human–human social spaces and investigate whether there is any comparable concept for human–robot social spaces. Other researchers have used social zones theory to guide investigations into human–robot interactions (e.g. Christensen and Pacchierotti 2005). Walters et al. (2005c) reported on experiments comparing human–robot approach distances to human personal space zones. Gockley and Mataric (2006) and Walters et al. (2005b) independently found relationships between human personality and human–robot approach distances. Michalowski et al. (2006) used a model of social engagement, which includes human-to-robot approach distance and direction, to assess human intent to interact with a robot.

This paper focuses on human and robot approach distances and robot-to-human approach directions. The generally recognized personal space zones between northern Europeans are summarized in table 1 (see Lambert 2004). The working research hypothesis advanced for the first study was that human–robot comfortable approach distances would be comparable to those found for human–human interpersonal distances. (Although human–human social space zones may not be directly applicable to human–robot social spaces, they provide an initial working hypothesis to help illuminate the correspondences between human–human and human–robot personal space zones.)

The second study tests the hypothesis that a seated human would prefer to be approached by a robot from directions with maximal visibility (Sisbot et al. 2005, Dautenhahn et al. 2006), such as a frontal approach with the robot remaining in full view. Although the two studies used different experimental set-ups and scenarios, and involved two different robot scenarios

<table>
<thead>
<tr>
<th>Personal space zone</th>
<th>Range (m)</th>
<th>Situation</th>
</tr>
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<tbody>
<tr>
<td>Close intimate</td>
<td>0-0.15</td>
<td>Lover or close friend touching</td>
</tr>
<tr>
<td>Intimate zone</td>
<td>0.15-0.45</td>
<td>Lover or close friend only</td>
</tr>
<tr>
<td>Personal zone</td>
<td>0.45-1.2</td>
<td>Conversation between friends</td>
</tr>
<tr>
<td>Social zone</td>
<td>1.2-3.6</td>
<td>Conversation to non-friends</td>
</tr>
<tr>
<td>Public zone</td>
<td>3.6+</td>
<td>Public speech-making</td>
</tr>
</tbody>
</table>
and behaviours, they complement each other because they investigate social spaces between humans and robots by addressing human–robot approach distance and direction.

2. The studies

Two multi-purpose studies were performed that involved human participants interacting with the PeopleBot™ robot in simulated living rooms. Documented here are the parts of these studies investigating human–robot social spaces. Other psychological and methodological aspects, results and outcomes from these studies are documented separately in Walters et al. (2005a, b), Woods et al. (2005, 2006), Koay et al. (2006) and Dautenhahn et al. (2006). The first study examined human-to-robot approach distance preferences in isolation (i.e. in a context-free scenario not involving any specific tasks); the second study investigated robot approach direction preferences for a simple object fetching task.

2.1 First study: human and robot approach distances

This exploratory investigation involved 28 participants in individual sessions interacting with a single robot in a simulated living room (figure 1). The main relevant objectives were to obtain measurements of human participants’ comfortable distances for approaching the robot and the robot approaching them. (Although there are cultural differences in social spatial zone distances (Pease and Pease 2004) and some participants in these trials originated from outside the UK, all participants were long-term UK residents and therefore could be presumed to have adopted human–human social distances similar to those found in the UK. Therefore, regional, cultural or ethnic origin information was not considered in the studies.)

A conference room was furnished as a living room with an enclosed section where robot operators and equipment were housed out of sight. The participants were 28 adult volunteers
(male 50%, female 50%) recruited from the University of Hertfordshire. Approximately 7% were 18–24 years old, 44% were 26–35 years old, 28% 36–45 years old, 11% 46–55 years old and 11% over 56 years old. Also, 39% were students, 43% were staff or faculty, and 18% were researchers. Approximately 50% came from a technology-related department. All participants completed consent forms and were not paid for participation, but at the end of the trial were given a book as a present.

Scale marks were made at 0.5-m intervals along the diagonal of the room (figure 2), and each experimental session followed the same format:

1. Entry to room and introduction of the robot. The robot approached and said, ‘Hello there’.
2. Habituation to the robot and initial questionnaires. While the participant was completing the questionnaires, the robot wandered randomly around the test area for 5–10 min before the distance tests to let the participant get used to the robot.
3. Social distance tests.
4. Various other human–robot interaction (HRI) tasks and questionnaires. (These latter parts were carried out for separate HRI investigations and are therefore not considered in this paper. See Koay et al. (2006), Walters et al. (2005a, b) and Woods et al. (2005) for more details.)

An experimenter introduced the procedure. To measure each participant’s comfortable distance when approaching the robot, the robot was driven to point 5 (next to the corner table) and turned to face along the distance scale towards point 4 (figures 2 and 3). The participant was told to start at point 4 and to move towards the robot until distance from the robot felt comfortable. Next, the participant was told to move as close to the robot as physically possible, then to move away again to a comfortable distance. The participant was then told to repeat these steps once again as a consistency check. The comfortable approach and withdrawal distances were measured for each of the two tests to the nearest 0.25 m (accuracy ±0.125 m) by later observation of the video records. Next, the comfortable robot-to-human stopping distance was measured with the robot moving from point 5 towards the participant. The participant was

![Figure 2](image-url)
told to stand at point 4 as the robot approached and to say ‘Stop’ when the robot was as close as desired. Although the robot typically overshot this distance, the actual distance at the time each participant said ‘Stop’ was estimated from observation of the video records.

2.1.1 Results. The means of the four comfortable approach distance results obtained were calculated for each participant and a frequency histogram plotted with the ranges set at 0.25-m intervals (see figure 4). For most participants (60%), the comfortable approach distance was within the personal and social zones, which, for humans, would be reserved for talking to friends, acquaintances and strangers.

When the robot approached a participant (see figure 5) the anti-collision safety system prevented it from moving closer than 0.5 m for safety reasons. However, approximately 40%
of the participants allowed the robot to approach right up to this 0.5 m limit. That they did not stop the robot before it approached this close indicates that the robot did not make them feel threatened or uncomfortable. This is confirmed in questionnaire results: when asked if they felt uncomfortable while standing physically close to the front of the robot, most participants (82%) indicated that they were not uncomfortable. Also, as less than 20% indicated that they wanted a robot for a friend or companion (Dautenhahn et al. 2005), these close approach distances did not express the participants’ wish to be intimate with the robot.

That many of the participants approached the robot closely, and tolerated a relatively close approach, implies that they do not perceive the robot as a social entity in the same way that they would another human. If another, unfamiliar human (a stranger) were to approach to the same close distances without a good reason, most people would feel distinctly uncomfortable and threatened. Interestingly, there was a small number of participants (approximately 10%) who were uncomfortable with letting the robot approach closer than the far end of the social zone (between 1.2 and 3.6 m), which is usually reserved for conversations between strangers.

2.2 Second study: robot to seated human approach directions

Fetching objects is likely to be a major task for domestic robots (Dautenhahn 2004). Two sets of robot-to-human approach direction trials were carried out in converted seminar rooms, where the scenario involved a robot using a front, left, or centre approach direction to bring a seated participant a TV remote control. Two sets of trials were performed to establish preferences for robot approach directions. The first was a demonstration event conducted as part of an evening of entertainment for convention delegates at AISB’05 (The Society for the Study of Artificial Intelligence and the Simulation of Behaviour, 2005 convention) and was performed under non-laboratory conditions with 38 volunteers. The follow-up study was carried out under controlled conditions with 15 participants; one of the main aims of this trial was to confirm the results obtained from the previous study. As both trial procedures were identical and in the light of the high degree of agreement between them, the results have been pooled to obtain a larger participant sample of 53 data sets. See Woods et al. (2006) for a separate analysis of both trials and Dautenhahn et al. (2006) for other aspects of the trials.

2.2.1 Experimental set-up. The trial set-up resembled a living room. The participant was seated in a chair, which was positioned halfway along the rear wall (point 9 in figure 6). Two
tables were arranged to the left front, and right front of the chair. A television rested on one of the tables and a CD radio on the other. Participants were truthfully told that the operator would control the robot while it was driven to the start position, but that it would autonomously bring them the TV remote control. This was reinforced as the operator made notes while the robot approached the participant (figure 7). (The operator was seated at a table in the far corner of the room.) The robot carried the remote in a small basket suspended between the fingers of the lifting gripper. For each approach trial, the participant took the remote from the basket then replaced it so that it would be ready for the next approach.
The experimenter introduced the scenario and explained the context to each participant as follows: the participant had arrived home, tired after a long day at work, and was resting in an armchair (point 9 in figure 6). After looking around for the TV remote control, the participant asked the robot to fetch it, as he or she was too tired to get up. The robot then brought the remote control to the participant. It was explained to the participant that the robot was new to the household, so it was necessary to find out which approach direction the participant preferred: front (2), left (1) or right (3). The three paths are shown in figure 6. The approaching robot was usually taller than the sitting person. Since most participants in both trials had never seen the robot before, we assumed that they would feel most secure, comfortable and ‘in control’ when the robot was fully visible and thus easy to monitor.

Since the TV might have been a natural focus of participants’ attention and perhaps influenced the choice of preferred robot approach direction, for the controlled lab conditions half the trials were carried out with the TV on the left-hand table, and the other half with the TV on the right-hand table. Each participant experienced the robot approaching from three directions: front, left and right. To avoid any order effects, a counterbalanced order sequence covering all six possible permutations of the three robot approach directions was used. For the demonstration event, participants experienced each approach direction only once, and for the controlled follow-up trials, each participant experienced the three robot approach directions twice. The order was again counterbalanced across all participants.

Thirty males (56%) and 23 females (44%) in total participated in the robot approach direction trials. The mean age of participants was 36 years (range: 21–58, SD: 11.54). Forty-nine participants (94%) were right-handed and three participants (6%) were left-handed. Before each trial, participants completed a short introductory questionnaire to give consent and demographic information. Participants also participated in a semi-structured interview after the follow-up trial. The main purpose of the structured interview was to assess participants’ views about the trial procedures and methodology and to find out how the trial could be improved. The participants’ reactions to the HRI trials were recorded by a single tripod-mounted camera placed at an appropriate point at either (5) or (6) in figure 6.

2.2.2 Results. Figure 8 shows that 59% (N: 31) of seated participants preferred the right robot approach direction, followed by 28% (N: 15) for the left and just 13% (N: 7) for the front. A large majority of seated participants stated least preferring the front robot approach direction (N: 43, 80%). Few seated participants least preferred the left and right approach directions.

![Figure 8. Direction preferences for the robot approaching a seated human.](image)
From the follow-up trial interviews and questionnaire responses, participants’ reasons for disliking the robot approaching from the front included the following:

‘I had to move forward to reach for the remote control; the robot was too far away from me.’
‘This approach was slightly threatening.’
‘This approach was just a little bit too close for comfort.’
‘Seemed too aggressive.’
‘The robot was always looking at me.’
‘I was concerned about the robot running into me during this approach.’
‘This approach was intimidating.’

3. Discussion and conclusions

Our results partially support the initial research hypothesis that human–human approach distances can be applied to robots. It must be emphasized that we do not claim that this means that these participants treated the robot as another person. These results could simply reflect a convenient distance for viewing the robot and might be influenced by the floor markings. It was not clear whether participants expected to interact with the robot, and this could also have influenced the approach distance. Therefore, more tests are required to confirm the reasons for these observations. Future work should investigate human–robot and robot–human approach distances, including a condition involving simple dialogue as compared to a simple approach condition.

The social distance experiments were performed before any other interaction with the robot. With habituation, the perception of the participants could change. It would therefore be useful to perform the distance experiments before and after exposure to the robot scenarios to see how participants’ responses change. There is also a need to perform long-term studies. The CERO robot assistant study (Severinson-Eklundh et al. 2003), the Robovie peer tutor robot trials with children (Kanda et al. 2004) and trials involving children with autism interacting with a humanoid robot (Robins et al. 2004) are examples of the few published works that describe studies of humans interacting with robots over long periods.

Results from the HRI approach direction trials indicate that most seated participants preferred a robot to approach from either side with a bias towards the right-hand side, which may follow handedness. The frontal approach was seen as uncomfortable and for some even threatening, and should thus be avoided. Future trials should investigate participants’ approach direction preferences in different situations (e.g. standing, sitting at a table, etc.).

The robot used in the trials had only a simple short reach gripper, so the object was presented to the participant in a simple lifting tray. If a longer manipulator or arm were fitted, the results might be different. It is desirable to perform further trials with different robots fitted with various types of arms and manipulators to see what effect they might have on user preferences.

It is likely that these results only generalize to mechanistic robots, but the work presented here is a first attempt to examine experimentally human–robot social zones, to provide socially acceptable default settings for mechanistic-looking robots. Further work is required to investigate how to make robots with a range of anthropomorphic features and behaviours more effective at human–robot interaction, so that users feel more comfortable.

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